management will work with Interior staff to ensure that the two efforts are coordinated. This year CAMP is providing about $90,000 to the Interagency Program to put their data into the IEP relational database.

CALFED Bay/Delta Program

CALFED's Ecosystem Restoration Program Plan contains three elements of particular interest to the Interagency Program — monitoring, indicators, and focused research. Over the next few months, these elements, including implementation, will be fleshed out. Interagency Program staff and management are critical in the development and review process as well as in implementation. In a recent meeting, Lester Snow, CALFED Program Executive Director, challenged the Interagency Coordinators to determine how the program should fit into the comprehensive monitoring and focused research efforts expected to come out of the CALFED process.

In late June, the CALFED Bay/Delta Program released its 1997 request for proposals called for under Category III of the 1994 Bay/Delta Accord. Up to $70 million will be available for approved Category III projects, although all of it may not be allocated in this round. CALFED staff received over 2,000 requests for the RFP. Some of the funding may go to support projects submitted by Interagency Program agencies, and some will be allocated to studies by consultants and university scientists who provide information essential to our understanding of estuarine and riverine processes. The challenge will be to integrate the new information into a collective ecosystem database and make it available to managers. The Interagency Program is a logical entity to take on this integration.

The CALFED Operations Group has been a major recipient of Interagency Program data and information. One program providing this information has been real-time monitoring, although the delta smelt, summer tow-net, fall midwater trawl, and salmon monitoring have also been important data sources. Both the Operations Group and Interagency Program staff are continually assessing information needs and revising the program to meet these needs, but budget, equipment, and personnel considerations often limit program flexibility.

UC-Davis EPA/NSF Grant

"An Integrated Approach to Assessing Water Management Options in Major Watershed" is a $1.3 million, 3-year grant from EPA and NSF to develop an integrated set of hydrologic, water quality, fish, watershed, and economic models of the Sacramento River watershed from Shasta Dam and Reservoir through the delta. The principal investigator is Paul Sabatier, who has nine co-principal investigators. Paul has organized an advisory committee, which includes Bruce Herbold and me for the Interagency Program, as well as Sam Luoma, chair of our Science Advisory Group.

The program has salmon modeling, temperature modeling, and delta particle tracking components, which are of particular interest to program staff. Coordination of this project with the Interagency Program will occur through participation in the advisory committee and on individual project work teams. We may be asking program investigators to share their information at a special session of the annual Asilomar workshop.

Proposal to NSF

A proposal, "Long-Term Ecological Research in Land/Ocean Margin Ecosystems — Trophic Consequences of Biological and Physical Fluxes in a Temperate Estuary", was forwarded to the National Science Foundation in late June. The proposal requests about $3.5 million over a 6-year period. The principal investigator is Wim Kimmerer, along with 14 co-principal investigators. The program has two components:

- Long-term research and monitoring to track variability in major ecosystem components and answer questions about potential mechanisms.
- Shorter-term studies to answer specific questions about the effects of flow or ocean conditions, mechanisms of response, and strength of trophic linkages.

Should the project be approved (they will know late this fall), the Interagency Program will be involved in several ways. Three of the co-principal investigators are program staff (Kathy Hieb, Karl Jacobs, and Jim Orsi), and I have been nominated to serve on the advisory committee. The Interagency Program database will provide data essential to carrying out the program objectives. Some of the work now conducted by the Estuarine Ecology Team will be counted as part of the state match. Finally, the Interagency Program's relational database may be the repository for much of the data coming out of these efforts.

Interagency Program Coordinators' Retreat

On July 30 (and perhaps July 31), the Coordinators will take this and other information into consideration in discussions to improve the present program and develop some future scenarios. In preparation for the meeting, the Coordinators will be meeting with about 20 key stakeholders and agency representatives to obtain their views on program direction. Results of the meeting will be made available in the October issue of the *Newsletter* and will be discussed at all program levels. Recommendations for significant program changes will be discussed at a meeting of the Management Level Advisory Group before being taken to the Agency Directors for consideration. The goal is to develop a long-term (5-year) plan to best meet the information needs of resource managers and regulatory agencies.

Spring Runoff Pulse from the Sierra Nevada

D.R. Cayan, D.H. Peterson, L. Riddle, M.D. Dettinger, and R. Smith

Abstract

A spring runoff pulse that makes the transition from low streamflow conditions in winter to the high streamflow conditions in the later spring and early summer is identified in the Merced River record from the Sierra Nevada. The timing of the pulse is delayed with greater seasonal accumulation of snowpack in the Yosemite region. Also, the runoff pulse is triggered by a regional weather fluctuation that establishes a warm high-pressure ridge over the California region during the spring (mid-March to Mid-May). This ridge often blankets the entire western United States, and it is found that a simultaneous pulse occurs over a broad collection of high-elevation streams in the region.

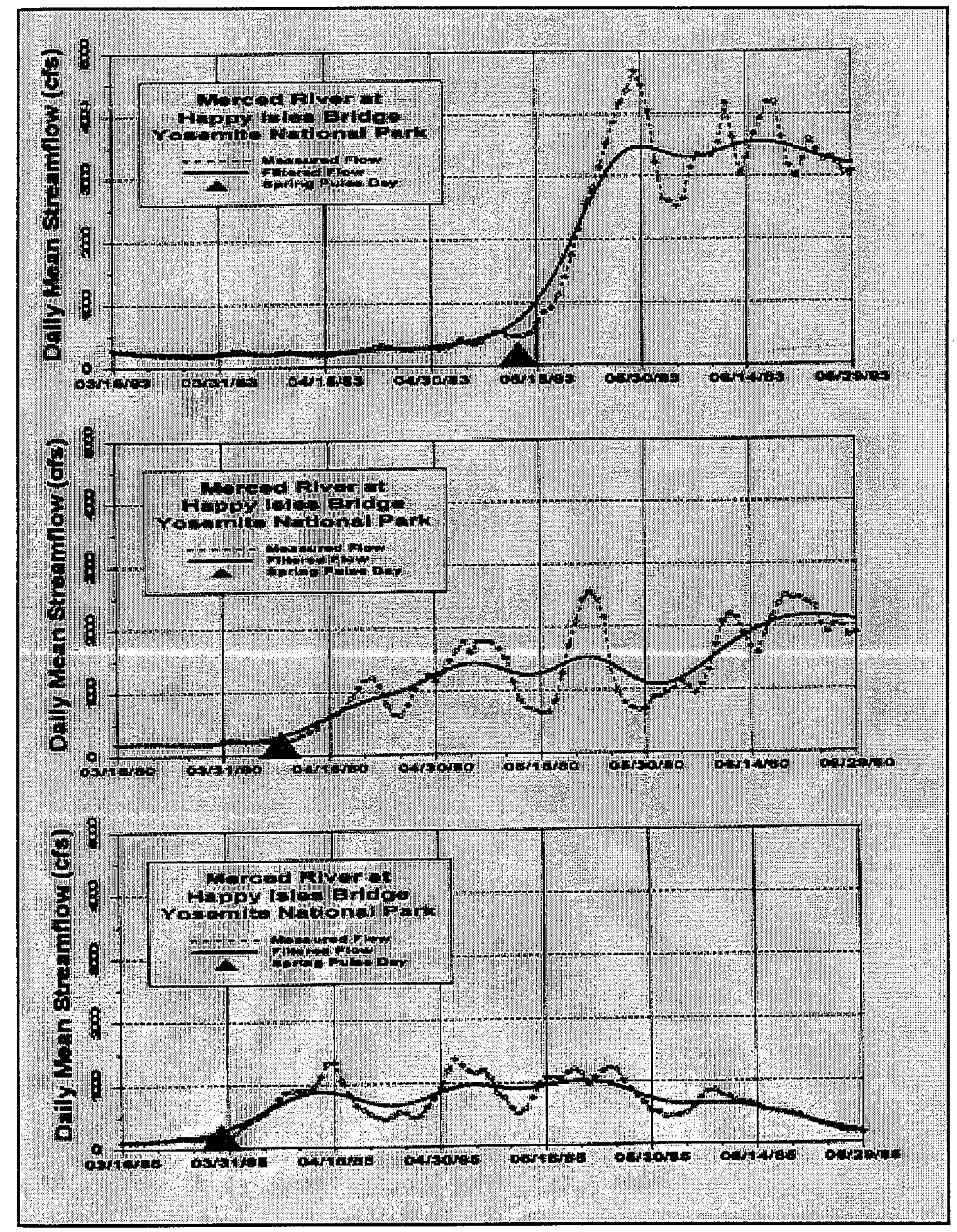

Figure 1
SPRING RUNOFF PULSE AT HAPPY ISLES GAGE,
MERCED RIVER, YOSEMITE NATIONAL PARK
Initial day of pulse is marked by triangle.
Solid and dashed curves show actual daily and smoothed flows for each of selected years.

Introduction

Snowmelt runoff from the Sierra Nevada constitutes a large component of the California water supply and contributes greatly to the freshwater budget associated with the San Francisco Bay system. Just about every year there is one pulse of snowmelt runoff (streamflow) that marks the transition of the Sierra climate from winter to spring. Three examples during the early 1980s from Merced River hydrographs show a very late spring pulse (1983), a very early spring pulse (1985), and a fairly average time of the spring pulse (1980) in Figure 1.

The record of daily flows (1948-1996) at Happy Isles, in Yosemite National Park, provides a convenient history from which we identified the spring pulse (Figure 2). On average, the pulse at Happy Isles occurs in mid-April, but it varies considerably - as early as mid-March and as late as mid-May. Also superimposed on the spring rise in streamflow are several day-long peaks and troughs in the streamflow that are the subject of companion studies aimed at modeling (Peterson *et al*, this issue) and prediction (Dettinger *et al*, this issue).

The marked increase in the flow over what would be expected from climatological spring conditions is shown in Figure 3, which is the composite streamflow of the Merced Happy Isles record corresponding to its spring pulse period, from the initial day through 19 days later. The composite is constructed from averaging 43 cases of Happy Isles Merced River pulse episodes. In comparison we show the climatological mean Merced streamflow over the same 43 years, but for the fixed period of April 19-May 6, which is centered during the overall average period of the spring pulse. A one-tailed *t*-test indicates that the rise in streamflow during the pulse period is greater than climatological streamflow at a high level of confidence ($\geq$95% confidence). It is not uncommon for the flow to increase three- or fourfold over the 20 days after the pulse begins; flow during the pulse period reaches values twice that expected by climatology.

But what causes it, and why is it so sudden?

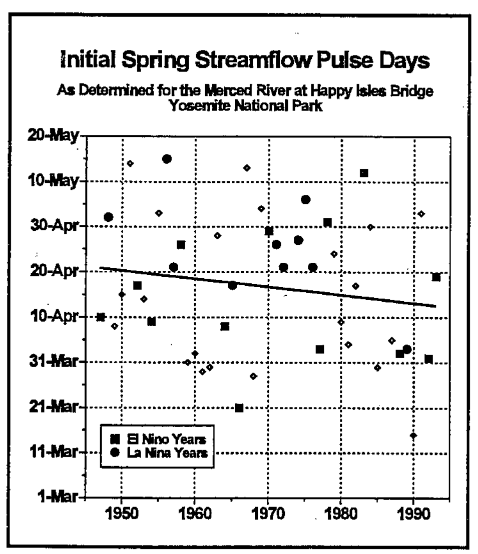

Figure 2
TIME HISTORY OF THE INITIAL DAY OF THE SPRING RUNOFF PULSE, 1948-1993)
Average time of onset is April 19, with a spread from March 15 to May 15. Note tendency for advance of pulse, about 7 days over the 48-year record. Also note tendency for spring pulse to occur later in spring during La Niña years (solid circles), while no decided pattern is evident during El Niño years (solid squares).

Two Influences: Seasonal Snow Accumulation and Spring Synoptic Weather Patterns

To get at the origin of the spring runoff pulses, we examined the history of the pulse times over the 48-year Happy Isles record (1948-1995) in Yosemite National Park in association with various climate and weather conditions.

First, in Figure 4, the Happy Isles record shows that the pulse comes earlier in years with low discharge (light snowpack) and later in years with high discharge (heavy snowpack). This may result from two effects - (1) the heavier the total annual flow, the more likely there is a "long" winter; and (2) the greater the snowpack, the longer the period of heating required to bring it to the melting state. Interestingly, the record (Figure 2) shows a subtle trend toward the pulse occurring earlier, amounting to an advance of about 7 days over the 46 years since 1948. Studies by Roos (1987, 1991) and Wahl (1992) have documented this trend; Aguado *et al* (1992) and Dettinger and Cayan (1995) have shown that the trend is from multiple factors but especially from warmer winters yielding earlier runoff in the Sierra. Dettinger and Cayan (1995) show that this trend is most pronounced in middle elevation snow-fed catchments, noting that the high elevation Merced basin contains some of this signal. Also, while there is not a useful link to El Niño years, there is a suggestion (Figure 4) that the springs following the mature phase La Niña events tend to have the pulse delayed from the climatological timing.

However, there is also a synoptic weather influence. Given the time of the pulse for each year, we composited (averaged) the 700-mb height anomalies and daily maximum temperature over a sequence from 5-days-before through 5-days-after the initial day of the pulse. For brevity, in Figure 5 we show the 700-mb height and maximum temperature anomalies only for the third day after the onset of the pulse. The 700-mb height is a good measure of atmospheric circulation (speed and direction of the winds, about 3 kilometers above sea level) and provides a history that covers the period since World War II. The composite sequence of 700-mb height anomaly maps clearly show that in many cases, the pulse is triggered by an orderly atmospheric pattern: a cool, wet period with a trough (negative 700-mb height anomalies) along the West Coast preceding the spring pulse moves through and is succeeded by development of a strong ridge of high pressure (positive 700-mb height anomalies) that blankets the western United States. This high-pressure ridge produces warm air and probably makes cloud-free skies - elements conducive to melting the winter snowpack. The companion maps of composite daily maximum temperature anomalies reinforce the picture of a cool pattern over the West evolving into a warm pattern. Average daily maximum temperatures are about 3°C above the long-term average in Northern California.

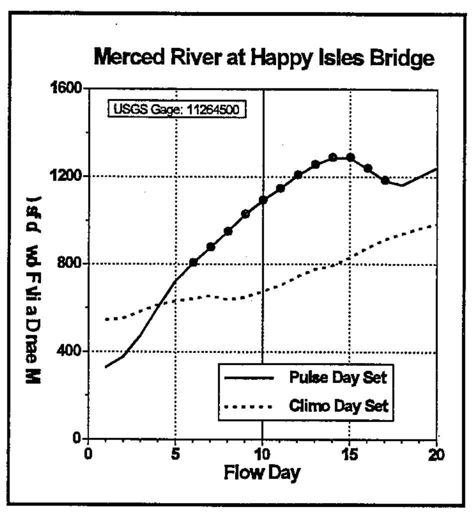

Figure 3
MERCED RIVER FLOW AT HAPPY ISLES, CORRESPONDING TO SPRING PULSE PERIOD, INITIAL DAY THROUGH 19 DAYS LATER
Solid curve is composite flow constructed from averaging 43 cases of Happy Isles Merced River pulse episodes. Dashed curve is climatological mean flow over same 43 years, for April 19-May 6. Dots indicate instances where the composite flow of the Happy Isles pulse days exceed the climatological flow with a statistical confidence level of 95%, from a one-tailed t-test.

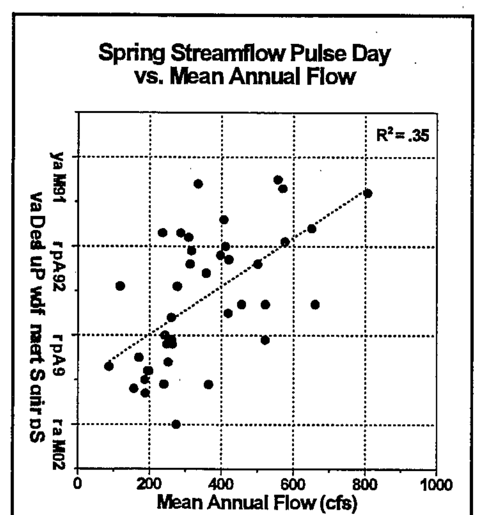

Figure 4
INITIAL DAY OF THE SPRING RUNOFF PULSE PLOTTED ACCORDING TO TOTAL WATER YEAR DISCHARGE
Higher discharge is associated with later spring snowmelt surge, accounting for 35% of the variance of the timing of the pulse.

The Spring Pulse as a Western U.S. Phenomenon

Because the atmospheric pattern that drives the runoff pulse covers a broad region, could it be that the Happy Isles record provides an index of spring high-elevation snowmelt over a much broader region?

An important feature of the 700-mb circulation and temperature anomaly maps described above is that they cover a large region, much broader than the Merced River basin or indeed the entire Sierra Nevada. Using the Happy Isles spring pulse record, a large set of 344 streamflow records from the USGS streamflow HCDN historical climate set (Slack and Landwehr 1992) was interrogated. After investigating the daily hydrographs from a variety of regions, we considered an index designed to measure the behavior of the western streams in association with the Happy Isles pulse from its inception to its completion. An initial investigation of the ensemble of spring hydrographs for other selected streams (not shown) indicates that other high elevation watersheds in the Rocky Mountains are surging above climatological levels at the same time as the Merced River spring pulse.

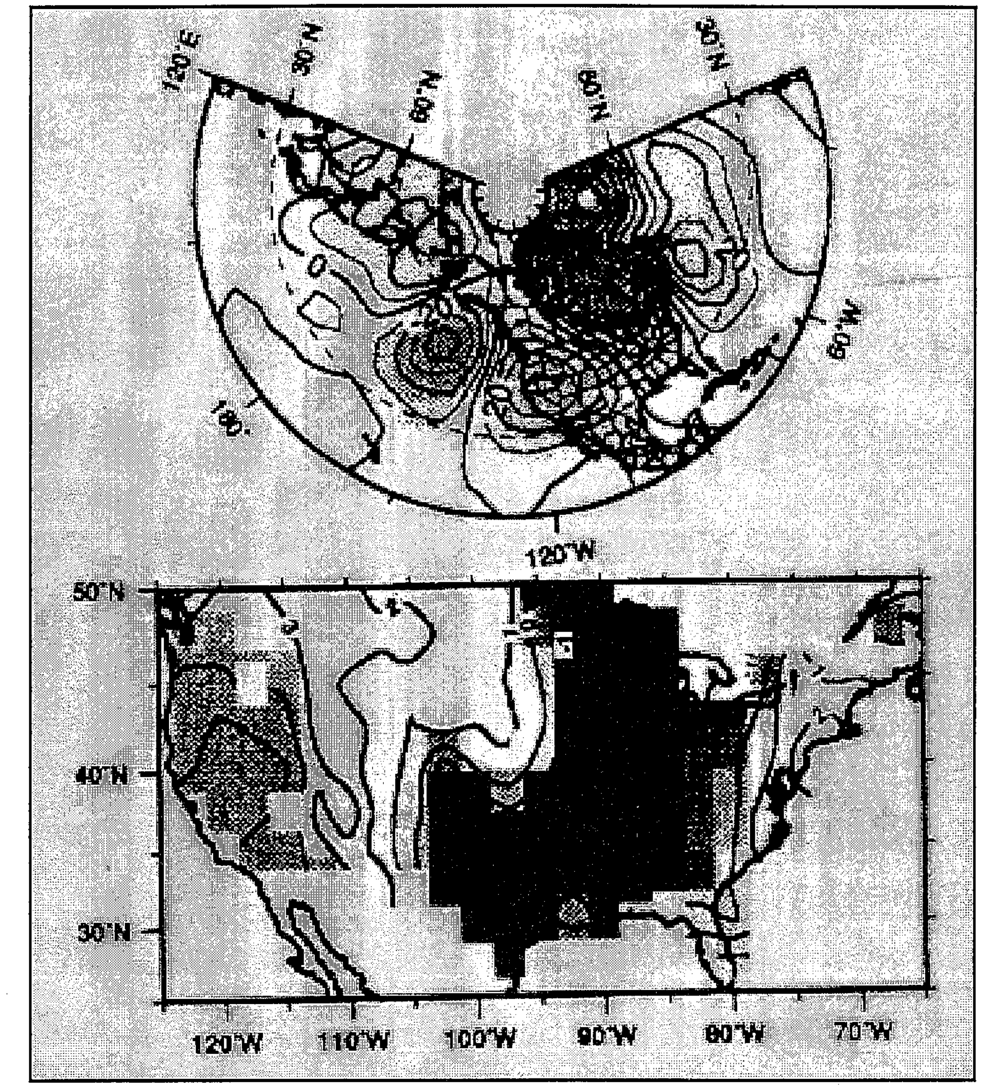

Figure 5
NORTHERN DAILY ATMOSPHERIC CIRCULATION AND MAXIMUM TEMPERATURE (T_{max}) AS A COMPOSITE ON THE THIRD DAY AFTER THE INITIAL DAY OF THE SPRING RUNOFF PULSE 700-MILLIBAR HEIGHT

Composite is average over 43 years of the 700-mb height anomaly field, gridded at 5° latitude by 10° longitude of the Northern Hemisphere; light/dark shading represents positive/negative 700-mb height anomalies (higher/lower than average pressure); contour interval is 10 meters. T_{max} data are a 2.5° gridded set from the first order and cooperative station observations. Shading represents warmer/cooler temperature anomalies; contour intervals at 1°F increments. Note how strong warming blankets the entire West, corresponding to development of high pressure ridge over the region.

Conclusions

High elevation Sierra runoff, as indicated by the Merced River Happy Isles stream gage record in Yosemite National Park, usually undergoes a pulse of high flow in spring that marks the transition from low winter flow to high spring/early summer flow. This pulse has considerably larger flows than would be expected from the increase in climatological mean flow in spring, and it usually has a much sharper rise. Because of this abrupt onset of the spring pulse, it would be valuable to understand and predict the character of the pulse in a given year. Both seasonal snow accumulation (late fall through spring), and spring atmospheric circulation play an important role in the timing of the spring pulse. Usually, a larger accumulated snowpack produces a later spring pulse. The spring weather pattern that triggers the pulse features a strong western high pressure ridge; this atmospheric forcing produces widespread warming presumably because of strong solar heating of the snowpack. Importantly, there is an overall coherent pattern of spring pulse over the high elevation watersheds in the West. Inspection of the western United States. stream gage dataset indicates that the Happy Isles record provides an index of the spring pulse over a much broader region of the high elevations, including the Sierra and the Rocky Mountains. Thus, the Merced Happy Isles gage provides a convenient index of a widespread western United States spring runoff pulse, although it may not be the optimum such index. Work to better elucidate this pattern and to identify coherent schemes for predicting the spring pulse is underway by USGS researchers, along with collaborations with Scripps Institution of Oceanography, NOAA Climate Diagnostics Center, and NASA Goddard Space Flight Center.

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Diagnosing the Flood of 1997 in San Francisco Bay with Observations and Model Results

Noah Knowles, Dan Cayan, Reg Uncles, Lynn Ingram, Dave Peterson

The flooding in January 1997 resulted from a series of very warm storms (freezing levels in excess of 9,000 feet) in late December through early January that followed the buildup of a massive snowpack from earlier storms in December. A more restrained sequence of storms in late January produced a second pulse of discharge, but this remarkable early winter was followed by the driest February/March period on record (California Department of Water Resources). The flood of January 1997 provides a unique opportunity to study the effect on San Francisco Bay of a strong freshwater pulse followed immediately by a very dry period. Total inflow during the 6-week period December 30 to February 9 is estimated to be 25x10^9 cubic meters, nearly four times the mean volume of the bay (delta flow shown in Figure 1). Water years 1983 and 1986 are the most recent years to exhibit such a high aggregate flow volume, with a smaller peak but a broader delta flow hydrograph in 1983 and a delta flow in 1986 that was nearly identical, though delayed, to that of water year 1997.

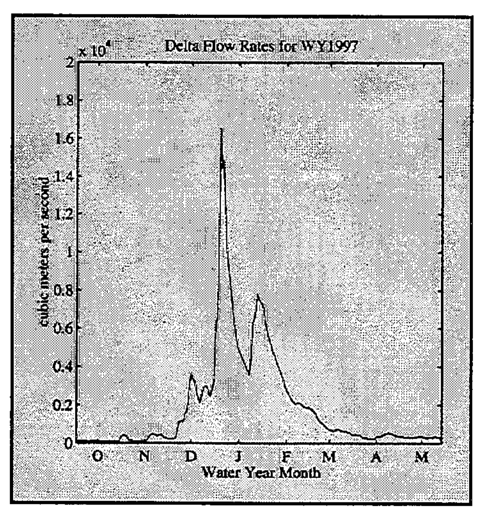

Figure 1
WATER YEAR 1997 DELTA FLOW HYDROGRAPH

During the course of this year's flood, multiple "snapshots" were taken of along-estuary and vertical distributions of salinity, oxygen isotopes, suspended sediment, chlorophyll and other important indicators of water quality (see USGS data at http://sfbay.wr.usgs.gov/access/wqdata). Here, the evolution of two tracers, salinity and the oxygen isotope ratio ($\delta^{18}O$), during the flood will be diagnosed with the aid of an intertidal water quality model, the Uncles-Peterson model. The model will be used to fill gaps in the observations, allowing a more complete examination of the flood's impact in the bay.

Model and Input

The Uncles-Peterson model (Uncles and Peterson 1996; Knowles *et al* 1995) uses coarse resolution (Figure 2) and tidally-averaged physics to generate simulations of the residual laterally-averaged velocity and salinity fields. Computations with the model are relatively fast, so a 40-year run on a current generation workstation takes only about 20 minutes. Also, the capability to simulate other solutes has recently been added and is being explored in light of the variety of data available to characterize the bay. The model is driven by precipitation, evaporation, ocean boundary salinity, an indicator of the spring/neap state of the tide, and freshwater inflows. To simulate the recent flood, delta flow estimates were provided by Sheila Greene (DWR), and local inflows were assumed to be proportional to the delta flow. Ocean salinity was fixed to its climatological mean, and precipitation directly over the bay was neglected. These assumptions were made due to lack of appropriate data, but the resulting errors should be minimal because tidal forcing and delta flow typically dominate the bay's variability.

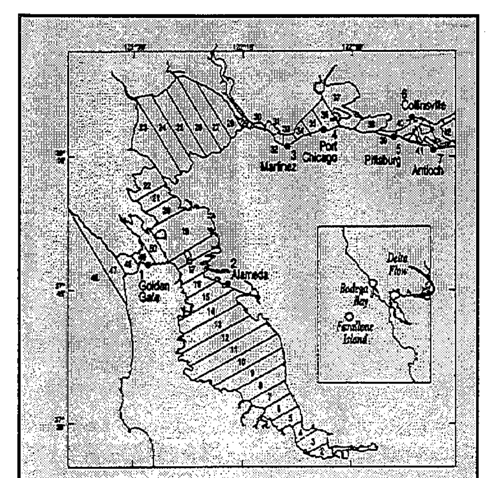

Figure 2
SEGMENTATION OF THE UNCLES-PETERSON MODEL

Salinity and Isotope Data

The data used to characterize salinity variability are from 14 cruises conducted by the USGS between October 16, 1996, and April 10, 1997. Salinity time series data were also provided by Larry Schemel (USGS, Menlo Park) at three stations in the North, Central and South bays. The oxygen isotope data are from four cruises between January 13 and April 1, 1997.These data provide a sparse but broad spatial and temporal coverage that, when used in combination with model results, yields a comprehensive picture of the flood's influence in the bay.

Results

Figure 3 compares model salinity results with the three time series. The model tracks salinity well at these stations, though it appears to overestimate South Bay salinity before the flood peaks and underestimate it afterwards. Comparison with the cruise data shows the same results, with good agreement throughout the bay and slight errors in South Bay. The problems in South Bay are partly due to the lack of local inflow data.

The evolution of the baywide salinity field is shown in Figure 4. Major features of the flood are apparent in the observed salinity data, and the model output fills in the gaps to provide a more complete picture of these events. The inflow pulse that initiated the year's salt field displacement was centered on December 15 and is visible from the delta seaward to about Angel Island. Subsequently, the peak floodwater inflows centered on January 1 and January 27 generate freshwater pulses that are distinguishable as far south as central South Bay. South of that they lose their coherence, but a model run with no local South Bay inflow clearly indicated the diffusion of delta water deep into South Bay. In another run, South Bay inflows were included, but delta water was specifically "tagged" to trace the movement of flood water through the bay. These model results suggest that average delta water content in South Bay rose from a typical dry-season value of around 5% before the flood to 35% after the peaks had subsided. This compares to an average value for the annual maximum delta water content in South Bay of around 20%, generated from a simulation of water years 1967-1993.

Figure 5 shows the evolution of the model bay's total freshwater content for the current water year as well as for a 27-year average. Although the peak freshwater content was nearly 30% higher during the 1997 flood than in the average year, the subsequent dry spell allowed freshwater content to quickly drop below the mean value, resulting in higher-than-average salinity despite the early-winter floods.

The model was run with the mean (constant) tidal state as well as the actual tidal state variations to examine the effect of variations in tidal mixing. The December 15 pulse was slightly stronger with tidal variations because it occurred during a neap tide. The January 3 pulse was initially strong during a neap tide, but the signal eroded quickly as a strong spring took effect. The January 27 signal was nearly as strong as the January 3 signal, even though the flows were significantly weaker. This was due to the setup from the January 3 pulse as well as a neap tide, which lasted for the duration of this event.